Defense Technical Information Center
Compilation Part Notice

ADP015001

TITLE: Moving Striations in a Low-Pressure Argon Plane Discharge. Self-Consistent Kinetic Model

DISTRIBUTION: Approved for public release, distribution unlimited

This paper is part of the following report:

TITLE: International Conference on Phenomena in Ionized Gases [26th] Held in Greifswald, Germany on 15-20 July 2003. Proceedings, Volume 4

To order the complete compilation report, use: ADA421147

The component part is provided here to allow users access to individually authored sections of proceedings, annals, symposia, etc. However, the component should be considered within the context of the overall compilation report and not as a stand-alone technical report.

The following component part numbers comprise the compilation report:
ADP014936 thru ADP015049

Moving striations in a low-pressure argon plane discharge. Self-consistent kinetic model

A.V. Fedoseev, G.I. Sukhinin

Institute of Thermophysics, Novosibirsk, 630090, Russia

In the paper, a self-consistent iterative kinetic model of stratified low-pressure argon glow discharge in plane geometry is presented. It is shown that striations moving from the anode to the cathode side of the positive column can be obtained from the consideration of non-local Boltzmann equation for electron distribution function and non-stationary continuity equation for ions coupled with Poisson equation for electric field.

1. Introduction

It is known that the positive column of a low-pressure glow discharge in inert gases often exists in a stratified form. Usually striations manifest themselves as moving waves. There were a lot of attempts to describe this phenomenon (see, for example, [1]). However, in most papers stratification was considered under the assumption of quasineutrality of the positive column, and the electric field was introduced from some additional consideration without taking into account the Poisson equation.

The stratification of a discharge is a collective phenomenon of mutual influence of electron and ion plasma components. In the paper, electron kinetics is considered on the basis of non-local Boltzmann equation coupled with the non-stationary ion balance equation and Poisson equation.

2. Model

A plane low-pressure discharge (p<1 Torr) is considered in self-consistent way. The influence of edge effects is neglected and the electric field is assumed to be axial.

The non-local Boltzmann equation in two-term approximation for the isotropic part of electron energy distribution function (EEDF) written in total energy–space coordinate representation was used:

$$\begin{aligned}&\frac{\partial}{\partial z}\left[\frac{U}{3H(U)}\frac{\partial}{\partial z}f_0(\varepsilon,z)\right]=\\&\frac{\partial}{\partial \varepsilon}\left[2\frac{m}{M}U^2N_gQ^d(U)f_0(\varepsilon,z)\right]+\\&\sum_k UN_gQ_k^{in}(U)f_0(\varepsilon,z)-\\&\sum_k (U+U_k^{in})N_gQ_k^{in}(U+U_k)f_0(\varepsilon+U_k^{in},z),\end{aligned}\qquad(1)$$

where N_g is gas density, U is kinetic energy of electron, $\varepsilon=U-e_0\varphi(z)$ is total electron energy, $\varphi(z)$ is potential distribution in the positive column (PC) of the plane discharge between the edge of the PC (z = 0 cm) and the anode (z=20 cm).

For ions, the non-stationary continuity equation in the drift approximation was considered:

$$\frac{\partial n_i}{\partial t}+\frac{\partial}{\partial z}(n_i\mu_i E)=n_e\nu_I,\qquad(2)$$

$\nu_I(z)$ is the direct ionization frequency, which in this paper is omitted, μ_i is ion mobility coefficient.

The coupling of the electron and ion components is provided by the Poisson equation for self-consistent electric field

$$\frac{\partial E_z}{\partial z}=4\pi e_0(n_i-n_e),\qquad(3)$$

For the solution of the system (1-3), the iterative numerical procedure was used. To obtain the first approximation of distribution function f_0^0(z,U), the parabolic equation (1) was solved as an initial boundary value problem from higher to lower total energies in some proposed electric field E^0(z). The numerical code is based on the solution of tridiagonal linear system of discrete form of Eq. 1, which is analogous to the Crank-Nikolson scheme [2]. Usually the constant field was chosen as the initial one. From the f_0^0(z,U), the electron density distribution n_e^0(z) was obtained. With the help of Eqs.(2-3), a new approximation of electric field E(z) was found, and the procedure was repeated until successive iterations of the electric field were converged. Usually ten iterations were enough for the procedure convergence. The final axial electric field distribution E(z) did not depend on the initial approximation E_0(z).

3. Results

As a result of numerical calculations, spatial evolution of the isotropic part of EEDF was obtained (see, Fig.1).

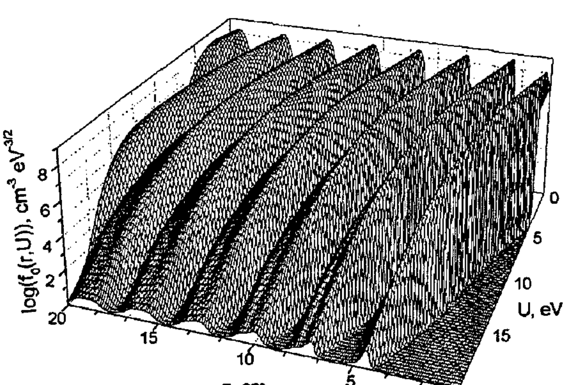

Fig.1. Three-dimensional representation of the isotropic EEDF starting from the cathode side edge (z=0) of PC toward the anode (averaged electric field E=4 V/cm, p=0.5 Torr).

It was found that the iterative process is converging only for the case of moving striations. In plane discharge, the solution for ion density and electric field were looked for in the form $n_i=n_i(v_it-z)$, $E=E(v_it-z)$, with the striation velocity $v_i=\alpha\mu_iE_0$, $0<\alpha<1$.

The velocities of moving striation have the value of averaged ion drift velocity, $v_i=\alpha\mu_iE_0$, with parameter $0<\alpha<1$. For $\alpha\leq0.25$ the used iterative procedure does not converge. With the increase of $\alpha>0.25$, the peaks of electric field in striations are decreased.

In Fig. 2, an example of self-consistent field distribution is presented. It is seen that electric field distribution has non-sinusoidal peak-like structure. The electron density distribution is almost in anti-phase with respect to electric field.

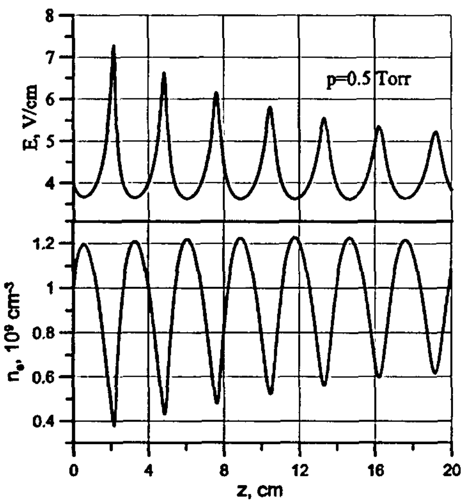

Fig.2. Electric field and electron density distributions in plane striated argon glow discharge (α=0.5).

It is found that for argon pressures p>1.5 Torr striations are damped due to energy losses in elastic collisions. For lower pressures, elastic losses result in small decay of striations to the anode side of PC.

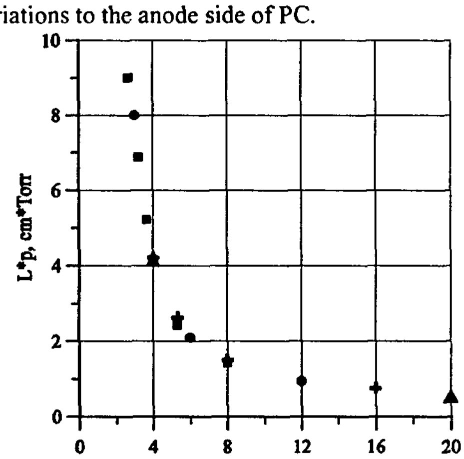

Fig.3. Striation length dependence on reduced electric field in plane glow discharge.

In Fig.3, the dependence of striation length on reduced electric field is shown. Results calculated for different argon pressures and electric fields fall into the unified curve. For given E/p, the striation length is inversely proportional to gas pressure, L~1/p. The length L slightly exceeds the minimal length necessary for an electron to attain the first excitation threshold $L>U_1/e_0E_0$.

In Fig. 4, the distribution of volume charge is shown for averaged field E=4 V/cm and p = 0.5 Torr. It is seen that double layers are formed in stratified PC. Relative deviation from the quasineutrality has the order of 10^{-2}-10^{-3}.

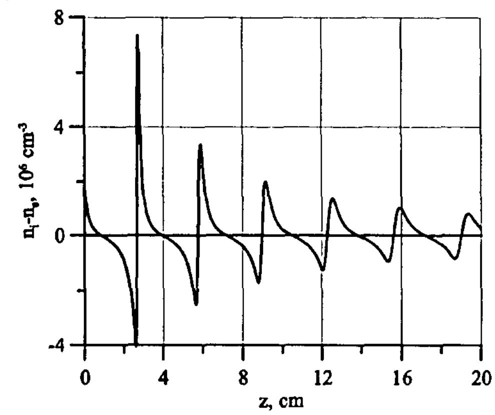

Fig.4. Volume charge distribution in stratified PC.

4. Conclusions

It this paper, a self-consistent model of moving striation in argon is presented. Non-local Boltzmann equation, non-stationary ion balance equation, and Poisson equation were considered simultaneously with the help of iterative procedure.

It was found that for low-pressure gas conditions the stratified regimes cannot be realized for the case of standing striations. However, consideration of moving striations permits us to receive a converged solution of the problem. Only the moving striations with the velocities directed from the anode to the cathode adjust the phase shifts between electric field and electron density distribution. The resonant amplification of peaks of distributions takes place.

The presented kinetic model is applied for low-pressure inert gases. At intermediate pressures, the stepwise ionization from metastable states should be taking into account. In this case, system of Eqs.(1-3) has to be supplemented with corresponding balance equation for matastable particles

5. References

[1] Yu. B. Golubovskii et al. *Plasma Sources Sci. Technol.* **11** (2002) 309.

[2] F.Sigeneger, R. Winkler, Contrib. Plasma Phys. **36** (1996) 551.

Acknowledgements

Financial support for this work was partly provided by the RFBR Grant No 00-03-32428, and by the ISTC Grant No 1425.